# 2.—SOME OBSERVATIONS OF SOLAR RADIOFREQUENCY RADIATION.

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## 1. INTRODUCTION.

The emission of radiofrequency radiation from the Milky Way was first observed many years ago (¹), but the emission of such radiation from the sun was not definitely detected until toward the end of the war when equipment developed for radio location was adapted for measurement of the solar radiation at various frequencies for comparison with the values theoretically predicted from blackbody laws. Whilst the results of measurements at the highest frequencies did not differ greatly from those predicted for a surface solar temperature of 6,000°C., at frequencies from 30 to 500 Mc/s the radiated energy, especially when large sunspot groups were visible, was found to be hundreds of times the expected values.

The observations described in this paper were made between May, 1946, and October, 1947. When they were started it was known that the energy radiated from the sun at frequencies of about a hundred megacycles per second increased with sunspot area, and especially with meridian passage of large sunspot groups (²), but nothing was known of possible correlations with other transient visible solar phenomena such as chromospheric flares. Some of the conclusions resulting from these observations were reached independently by other observers, on whose work information was subsequently received. In such cases acknowledgment is made in the course of discussing the results.

During this period, theoretical understanding of the processes in the solar atmosphere giving rise to the radiofrequency radiation was also advanced (¹, ³), and these contributions are taken into account in discussion on the source of the noise radiation at the conclusion of this paper.

## 2. APPARATUS.

By the courtesy of the Director of the C.S.I.R. Radiophysics Laboratory at Sydney the author was loaned two 75 Mc/s radar receivers. With assistance from the staff of the laboratory design data for a Yagi aerial, consisting of a folded half-wave dipole, reflector and two directors, was obtained for 65 Mc/s and scaled up to the operating frequency. An aerial constructed to this design was mounted on a crude polar axis (without automatic drive) and provided with movement in declination. The elements were so oriented that horizontally polarized radiation was observed. Although maximum sensitivity in the forward direction is desirable, construction difficulties at 75 Mc/s are formidable for any but the Yagi type of aerial and ability to detect anything but marked emission was sacrificed for portability and simple, cheap construction.

The noise factor of the receiver, measured in the Radiophysics Laboratory, was about seven. Two years later it was measured in the Physics Laboratory of the University of W.A. and found to be nine. It cannot be assumed that this characteristic did not change during operation, and this together with the lack of appropriate apparatus for assuring accurate balancing of the aerial to receiver and for measuring more than very crudely the effective gain of the aerial in the forward direction, prevented any serious consideration of absolute values of received power. In the beginning the variable elements of the aerial, lengths of dipole, reflector and directors were adjusted for maximum sensitivity to horizontally polarised radiation from a transmitter mounted about a hundred yards distant on a flat roof. Reflection from the roof interfered with efforts to obtain a polar diagram.

At first visual, and later photographic observations, were made of the variation of the anode current of the second detector. The linearity of this detector to input voltage was confirmed by laboratory tests and care was always taken that receiver gain was decreased sufficiently to ensure that only in exceptional cases would the maximum load current of the detector be reached. Observation of receiver noise current ($I_N$) using a dummy aerial load at the input, and of the receiver noise plus solar noise current ($I_{S+N}$) when connected to the aerial, was used to determine received solar noise.

If the set noise input power is $W_N$ and the solar noise input power $W_S$ then $I^2_N = CW_N$ and $I^2_{N+S} = C(W_S + W_N)$

(C being a constant for the linear detector)

$$(I_{S+N} - I_N)^2 = I^2_{S+N} + I^2_N - 2I_{S+N} I_N$$

$$= CW_S + CW_N + CW_N - 2C\sqrt{(W_S + W_N) W_N}$$

$$= CW_S - 2C W_N(W_S + W_N - W_N)$$

$$\text{So } CW_S = (I_{S+N} - I_N)^2 + 2C\sqrt{W_N}(\sqrt{W_S + W_N} - \sqrt{W_N}($$

$$= (I_{S+N} - I_N)^2 + 2I_N(I_{S+N} - I_N)$$

$$W_S \infty (I_{S+N} - I_N) (\overbrace{I_{S+N} - I_N} + 2I_N)$$

Where $I_{S+N} - I_N$ is the height of the disurbed trace above the undisturbed level. This expression was used when accurate measurement of the solar noise power was required, as for example in examining the shape of the pulses (*see* Section 5).

Initially photographic recording of the " grass " pattern of a Cathode ray oscillograph was attempted, the trace being moved along the X-axis and observed as it passed behind a narrow slit parallel to the Y-axis. By using the synchronous motor driving the camera to close a circuit and light a pealamp behind the slit, a time mark was put on the film every 75 seconds. While this system showed up violent short-period disturbances it could not provide any useful indication of the magnitude of solar-plus-set noise current and was soon replaced by a more satisfactory method.

A portable Tinsley vibration galvanometer with a suspension unit designed for operation on 50 cycles was modified by (a) detuning it to resonate at about 45 cycles compared with the local power frequency of 40 cycles, (b) altering the optical system to provide a small spot instead of an extended disk on the scale, (c) shunting the coil so that the sensitivity was about 16 mm. per millampere D.C. and the damping such that the spot came to rest after a sudden deflection in about 0.25 seconds, and (d) adding series resistance to make up the correct load in the anode of the detector.

By means of reflection in two 90° prisms the horizontal deflection of the galvanometer spot was changed to vertical deflection at the camera lens. The image on the film was reduced about three times. A simple camera box using 35 mm. film passing over a sprocket driven by a synchronous motor was constructed in the laboratory workshop. Film speed was about 12.15 mm./minute, or about 10 feet for a normal, daily, four-hour run. A properly focused and exposed trace allowed resolution of consecutive peaks occurring within two seconds and it was found feasible to project the films with magnification about 30x, under which conditions the centre of the trace could be determined with a linear accuracy corresponding to 0.25 second.

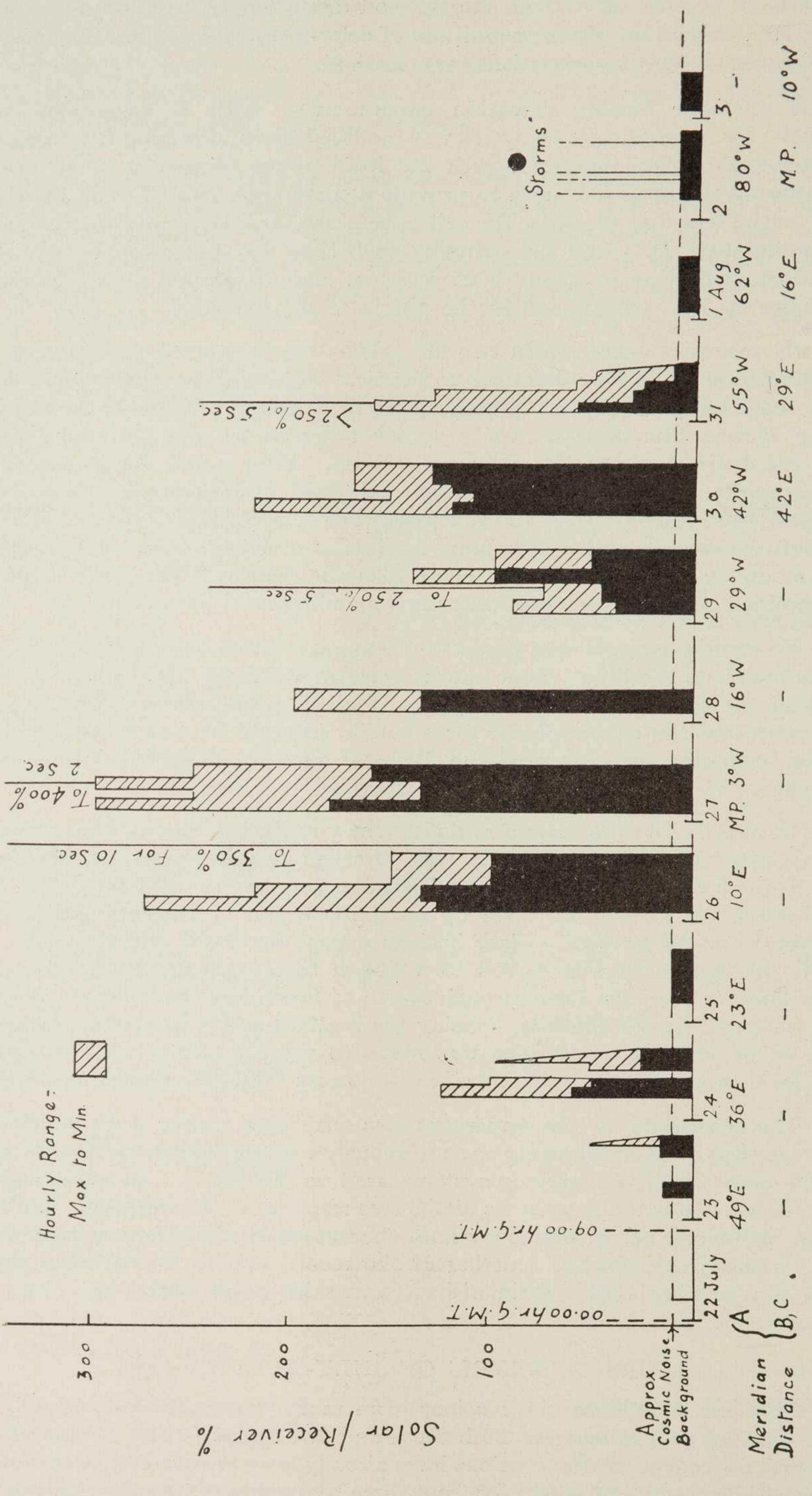
No serious attempt was made to photograph either time marks or a scale of ordinates on the film. Time marks were made about half-hourly by connecting the set input to a dummy load for thirty seconds and subsequently disconnecting the galvanometer for a similar interval to record the zero line. When ordinates were required the film was suitably projected onto a ruled screen.

In initial tests the cosmic radiofrequency radiation was used as a source. An increase of about 20 per cent. was observed in noise current as the aerial was turned towards the centre of the galaxy from the galactic pole. The apparatus was at that time set up on the flat roof of Hackett Hall at the University of W.A. with a clear horizon except for 30°N. and S. of W. In 1947, the apparatus was moved to a site in the University grounds with a clear horizon from the East through North to West, but the Southern horizon was obscured by the building housing the receiver and a spectrohelioscope as well as by trees. No attempt was made to use the cosmic radiofrequency flux level as a calibrating source, since site errors would have been too serious.

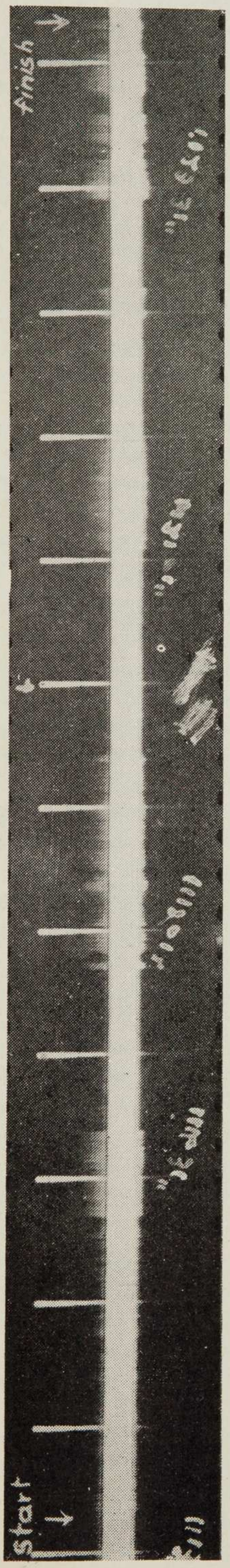
The sensitivity of the apparatus was such that under quiet conditions the trace was quite flat showing no continuously varying deflection characteristic of the more sensitive receiving systems used on 200 Mc/s. An advantage of the vibration galvanometer is its distinctive response to interference. Ignition noise, switching, power frequency hum characteristic of diathermy apparatus, etc., is shown by marked blurring of the record due to the widened trace. This can be very easily distinguished from solar noise variations.

## 3. OBSERVATIONS OF JULY–AUGUST, 1946.

The first significant observations were made during the passage of two large sunspot groups between 20th July, and 3rd August, 1946. Some of the conclusions from these observations have already been recorded ([4]). Continuous observations were maintained for from three to five hours each day, during the



Text Fig. 1.—Solar Noise Level Perth, W.A. Hourly Ranges 75 Mc/s 22/7/46 to 3/8/46.



Text Fig. 2.—Disturbance observed on 2nd August, 1946, 03.14 U.T. to 03.29 U.T.

The time marks are 45 sec. apart.

passage of the large sunspot group A, situated in Lat. 24°N., Long. 197°, with mean meridian passage on 1946 July 26.7 (G.M.T.) and the two following groups, B and C, situated in Lat. 9°N., and 29°S. and Long. 110° and 108°, with mean meridian passages on August 2.25 and August 2.4 respectively. These observations are plotted in text fig. 1.

The following conclusions were reached regarding the nature of solar radiofrequency radiation :—

(i) For convenience, solar radiofrequency noise can be divided roughly into two types, the one "steady" or relatively slowly variable (Component I), the other abruptly variable (Component II).

That a similar distinction had independently been made by McCready, Pawsey and Payne-Scott ($^5$), came to the author's notice at a much later date.

While Component I. is possibly the statistical resultant of a large number of processes whose fundamental mechanism is the same as that giving rise to Component II., the actual developments causing the emission of the two types must differ considerably in many respects and significant distinctions have been found (*see* Section 7).

Component I. was very strong during the passage of group A across the solar disk. Its existence was postulated as a result of examining the ratio of maximum to minimum solar-plus-receiver/receiver noise obtained during each successive full hour's observation. In twenty-eight hours spread over ten days, there were only four hours during which this ratio exceeded two, three of these occurring on 31st July. Excluding fluctuations to higher levels occurring for but one or two seconds, which were observed on a relatively small number of occasions, no variations comparable with those observed on 2nd August (*see* below) were seen.

(ii) Component I. can be emitted from a spot region which is showing no marked activity when observed with the spectrohelioscope. For example, on July 28–30, the flocculi associated with group A were diminishing in intensity according to spectrohelioscope observations made at Watheroo Magnetic Observatory, but the noise was still very high.

(iii) The strength of Component I. cannot be related simply to the passage of the spot across the central meridian. In text fig. I. are shown the relative levels observed on 13 successive days, maximum and minimum values being indicated. The higher noise levels were observed when the group was West of the meridian. The level was also higher on 24th July and 30th July, than on the adjacent days when the meridian distance was less.

(iv) The magnitude of Component I. is apparently dependent on some as yet unidentified activity over the spot area itself, possibly associated with the previous occurrence of solar flares. In contrast to group A, groups B and C, which were of much greater than average area, showed no significant emission of Component I. when on and to the West of the central meridian, group A having rounded the West limb. The noise observed on 31st July was, therefore, attributed to group A. No exact information is available with regard to the flocculi associated with the two later groups, though it is understood that these spots were less active than group A. The level of Component I. does not appear to correlate simply with spot number or area.

(v) The variable Component II. changes by very large amounts in one or two seconds. A striking example observed on 2nd August is shown in text fig. 2, a reproduction of the film record of the cathode ray trace. From comparison with two less intense, but similar disturbances, which were recorded on both meter and film, it is estimated that this " storm " involved increases in noise power by 50 to 100 *times* in a second or two. The width of the undisturbed trace indicates the normal noise mean amplitude, which included solar noise amounting to about 10 per cent. of that from the receiver. During most of the disturbance the trace extended beyond the limits of the stop over the oscillograph screen, which implied an increase in amplitude of the trace of two to three hundred per cent. Timemarks occur every 75 seconds and intervals of three seconds can be resolved. The abrupt variations are totally different from any solar phenomenon observed visually. Close examination of the original record shows that the more intense bursts of radiation consist of separate peaks spaced on the average 2.5 seconds apart. Their apparent width is dependent on the width of the slit covering the oscilloscope screen.

## 4. OBSERVATIONS MARCH–SEPTEMBER, 1947.

During the period March-September, 1947, an effort was made to record during the period 10.00–14.00 hour local time, on five days each week. About 450 hours' recording was made on 126 days.

Based on the observations of July-August, 1946, disturbances were classified according to duration with, initially, an arbitrary limit of five minutes for those to be classed as Component II. Three disturbances observed in May and June, which were similar in duration to those observed on 2nd August, 1946, were of a nature conflicting with this arbitrary criterion. At the same time they were judged from their high flux level particularly, to be physically distinct from the normal short-lived disturbances and evidence given in the next section regarding their correlation with visually observed solar changes supports this conclusion.

Of the 126 days, on only five certainly, on one doubtfully, and for three short periods of less than an hour each, was radiation of the type Component I. observed. Of these days two pairs were on consecutive dates. Apart from the short periods, of which two are doubtful, Component I., when observed, was very marked throughout the observing period. A characteristic record was always produced. Sunspot conditions on the five days are described below.

The high level of noise on 10–11th March was undoubtedly connected with the central meridian passage of the large spot group on the 10th. On the 12th, the level was back to normal. No observations were made in the seven days preceding 10th March.

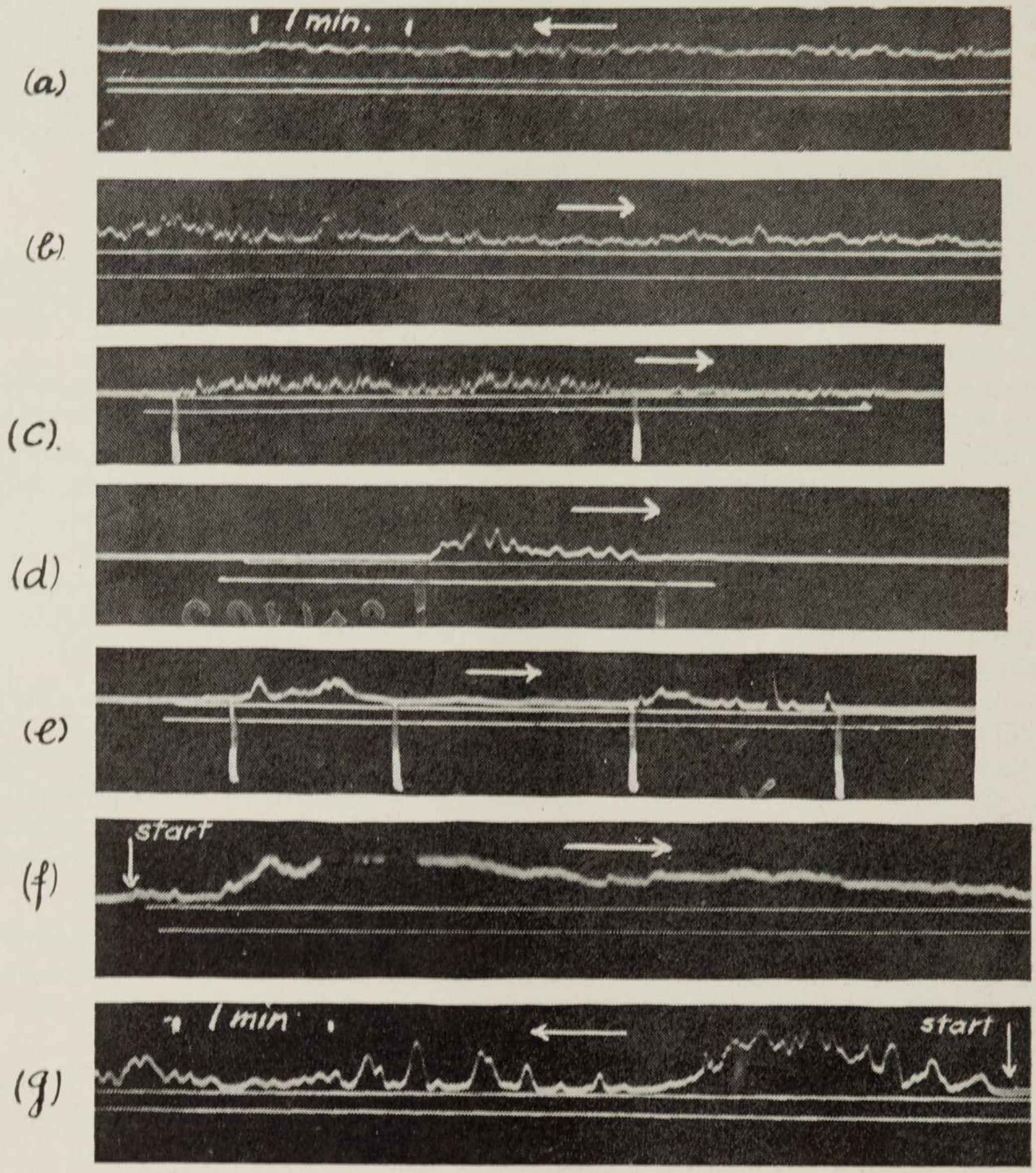
On 10th and 12th June there was no abnormal noise, although it was observed on 11th June. Group 8611 (Mt. Wilson) crossed the central meridian on 9th June.

Only small sunspots were near the centre of the disk on 20th June with central meridian passage June 22.0.

On 25th September, when a large active bi-polar group, Mt. Wilson No. 8823, crossed the meridian no type I. radiation was observed, although radiation of this type was observed for two hours on the previous day and the whole of the following day. The radiation level was not at all high, but the frequency of occurrence of pulses was at times very high.

The conclusion of Section 3, namely, that the level of type I. radiation does not depend essentially on meridian passage is supported by these observations. The fact that large sunspots passed over the disk on several occasions without producing an appreciable increase in the level shows that sunspot area is likewise not the essential factor.

Disturbances classed as Component II. were observed on 74 of the 126 days and numbered 250, or about one per hour for disturbed days or one per two hours for all days. The average duration of these disturbances was about one minute, though they range from single peaks lasting ten seconds or less, to a series of ten or more, lasting nearly five minutes.



Text Fig. 3.—Examples of solar noise records. The position of the galvanometer spot for zero current and for receiver noise current is indicated by the straight lines. The arrows show the direction of time. (a) 10/3/47: Type I with high level background. (b) 26/9/47: Type I with low level background. (c) 27/5/47: Short lived Type I, 0331-0335, U.T. (d) 3/9/47: Type II, 0219-0221 U.T. (e) 27/5/47: Type II, 0508-0512 U.T. (f) 16/5/47: Large Type II disturbance, 0328-0337 U.T. coincident with large flare. (g) 30/9/47: Part of large Type II disturbance, 0236-0248 U.T.

On five occasions in addition, were observed disturbances of exceptional intensity classed as Component II., but of average duration 12 minutes and consisting in part at least of overlapping peaks superposed on a high flux level. The two disturbances observed on 2nd August, 1946 (0314–0329 G.M.T. and 0451–0457½ G.M.T.), could also be classed in this group.

Examples of the various types of disturbances are illustrated in text fig. 3.

In no case, on records of either type of disturbance was there observed such an abrupt change of flux level that the galvanometer, in following, left no photographic record. In other words, increase or decrease of radiation flux from base to peak or vice versa was never observed as occurring in an interval less than about one second, although the galvanometer was capable of following changes occurring fifty times faster. This characteristic became in fact the chief criterion for rejecting as spurious apparent disturbances observed occasionally and subsequently traced at times to operation of a laboratory oscillator. This aspect of the records is discussed in more detail in Sections 6 and 7.

From the 450 hours' observation it is concluded that sustained noise (Component I.) is observed rarely, depending on the presence near the centre of the disk of large and active sunspots ; that short bursts of pulses lasting about a minute (Component II.) are comparatively frequent, with a tendency to concentration on disturbed days and that violent short-lived disturbances, such as that illustrated in text fig. 2, are comparatively rare.

## 5. CORRELATION OF NOISE DISTURBANCES WITH VISIBLE SOLAR PHENOMENA AND IONOSPHERIC FADEOUTS.

In the latter of the two periods of observations discussed (1947), chromospheric flares or ionospheric fadeouts almost certainly resulting from flares, were reported from Canberra, Kodaikanal or Watheroo Observatories on forty occasions when noise records were available. A partial analysis of the data has already been published. ($^6$).

On twelve of these occasions, including nine flares of importance, 1, 2 flares of importance 2 and one noise storm observed on 200 Mc/s. of a type considered to be simultaneous with a flare, no noise disturbances were recorded on 75 Mc/s. during the four hour observing period in which the solar disturbance occurred.

On only one occasion (16th May, 1947) was there observed simultaneous occurrence of flare and 75 Mc/s. noise. The flare (Kodaikanal, importance 3) started at 0329 U.T. with a maximum brightness at 0337 and ended at 0342. A violent noise disturbance started at 0328, continuing till 0338.

Two other violent disturbances were recorded nearly simultaneously with ionospheric fadeouts and noise disturbances on 200 Mc/s. observed at Canberra and thought to coincide with flares. These were :—

4th June, 1947.—Canberra fadeout, 0300–0445 U.T., 200 Mc/s. noise 0304–8 ; Perth 0310–32 violent noise.

5th June, 1947.—Canberra fadeout 0220–0330, 200 Mc/s. noise 0237–9, 0302–8 ; Perth 0237–0302 violent noise.

There were nine occasions when one, or a few, medium to small pulses were recorded during a fade or flare. On five other occasions simultaneity was doubtful or the noise was very slight. On three occasions in addition to the twelve first mentioned there was no simultaneous noise.

It would seem that only with large flares can simultaneous noise production be expected with reasonable probability. Since Component II. disturbances are observed on the average hourly on disturbed days, the above results do not indicate much more than chance coincidences.

The 1946 observations provided interesting material on 2nd August. The disturbances shown in text fig. 2 started at 03h. 14m. 10s. (approx. G.M.T.) and finished at about 03h. 29m. 10s. The report on spectrohelioscope observations supplied from Watheroo Magnetic Observatory, reads :

> "Aug. 2. Conditions clear. Observing times : 00 : 45 GMT to 01 : 00 GMT, 03 : 15 GMT to 03 : 30 GMT, 05 : 00 GMT to 05 : 15 GMT. Observations made between 00 : 45 and 01 : 00 showed that the various spot groups were not active and the flocculi about these spots were rather faint. Between 03 : 15 and 03 : 30, while scanning the sun's disk, it was noticed that a bright prominence (intensity 1) had appeared on the N-W limb above the leading spot group. This prominence appeared to be of the active type known as "eruptive prominence." It was also noticed that the flocculi about the spot group were active. By 03 : 30 the prominence had faded considerably. None of the other groups showed activity and the flocculi were faint."

A similar, but less intense disturbance, during which the milliameter showed increases in solar/receiver noise from 10 per cent. to more than 150 per cent.—the pointer left the scale for a few seconds—was recorded on the same day between 04h. 51m. and 04h. 57m. 30s. (G.M.T.). Ionospheric equipment at Watheroo recorded a fadeout of intensity 4 (scale 1–9) from 04h. 45m. to 05h. 00m. The Watheroo spectohelioscope report reads :

> "At 05 : 00 a rather faint prominence was seen over the spot group on the N-W limb. In appearance it was similar to the prominence seen at 03 : 00 but appeared narrower and made up of vertical streaks. By 05 : 07 this prominence had disappeared. The flocculi about the spot group appeared to be active."

Similar disturbances recorded on the same day, from 03h. 59m. to 04h. 04m. 10s. and 07h. 27m. to 07h. 30m. were not accompanied by fadeouts and the sun was not under observation at Watheroo.

It has not been possible to check whether noise disturbances of Type II. occur when no flare is observable since the observing hours for spectrohelioscopes were not supplied. However, reasonable assumptions as to the period of use of spectrohelioscopes before and after observation of recorded flares and the non-appearance of ionospheric fadeouts, indicate that pulses of radiation do occur outside the times of recorded flares.

Whereas only once was noise radiation observed to precede a flare and then possibly noise of Type I. rather than Type II., on twelve occasions noise followed a flare with less than 30 minutes delay and on seven other occasions subsequent noise was either delayed longer, or was very slight. Only on 4th June, 1947, and 5th June, 1947, in addition to the twelve occasions when noise was nil, was no subsequent noise observed.

In view of suggestions (³) that noise originates in the lower corona as a result of plasma oscillations excited either by ultraviolet light or corpuscular bombardment, delayed as well as simultaneous noise might be connected with a flare. It is to be expected that excitation by ultraviolet radiation would presuppose increased emission in H$\alpha$, i.e., a flare, at the same time as the ultraviolet emission increases. If corpuscles excite the plasma oscillations they may or may not originate from a flare. If they do come from a flare, the interval between flare and noise will depend on their velocity and the height in the corona at which the excitation takes place. Observations supporting this view have already been published (⁷).

Phenomena involving corpuscular emission, such as aurorae and magnetic storms following the meridian passage of large spots can occur independently of flares, so that the assumption that corpuscular emission causing plasma oscillations can also occur without observation of flares would not be novel. The observation of 2nd August, 1946, namely a violent noise storm lasting 15 minutes, occurring as an eruptive prominence was seen to develop from an active area suggests corpuscular excitation of the corona as a possible mechanism.

Since 75 Mc/s radiation received at the earth cannot have penetrated electron densities greater than about 108/cc. in the solar atmosphere, noise generated by radial emission from centres a considerable distance from the central meridian would only be received in exceptional circumstances. This consideration might explain why two flares of importance 2, occurring 60E. and 61W. of the central meridian respectively were not associated with noise. It would not explain why one flare of importance 2, 4°E. and three flares of importance 1 occurring less than 15° from the central meridian were not associated with noise.

## 6.—SHAPE OF PULSES OF TYPE II. RADIATION.

During the 1947 observations, single pulses of radiation of Type II. clear of overlapping pulses were observed on about 100 occasions. In view of the ability of the recording galvanometer to follow changes in noise current much more rapid than those actually observed, it was considered reasonable to accept the galvanometer trace as a true record, taking into account the linear detector, of the variation of radiated power with time. Interest in this question was stimulated by the observation of a number of large single pulses having very marked " tails ", which looked as though they might obey some ascertainable law of decrease.

The " tail " of the pulse indicates the manner in which the source of radiation falls off in radiating power. The simplest case is that of a source possessed of a certain energy by reason of its oscillations and receiving no energy from outside. If the rate of decrease of energy in the oscillations and hence of radiation of energy is proportional to the energy in the oscillations, the power-time curve will follow an exponential law, $P = P_0 e^{-xt}$. The energy loss need not be exclusively by radiation so long as the relationship holds. Collision damping might be involved for instance.

Suitable pulses were therefore projected with a magnification about 30x and the centre line of the photographic trace of the film was recorded at a scale of one inch to four seconds. The measured ordinates were then converted to relative power levels by using the formula given in section 2 and their successive ratios at constant intervals of time (0.4, 0.5 or 1.0 sec.) were examined for variation about a mean value. The smaller this variation, the nearer to exponential is the curve.

Of 132 tracings made, 28 were rejected as poor curves due to the presence of small overlapping pulses and five were fronts of pulses only. Of the remainder, 21 were good curves, but the height of the pulses was small, less than 25% of the set noise background and the length of falling slope was considered too short to provide a worthwhile result. The remaining 78 were then classified according to their approach to exponential form. A variation of 15% or less about a mean value of the exponent was taken as satisfactory and 58 came within this category. These were then assumed to be very probably exponential. Eleven were less probably exponential, four probably not so and five definitely not so.

As examples of the first, second and fourth categories, pulses Nos. 72, 26 and 76 are quoted :—

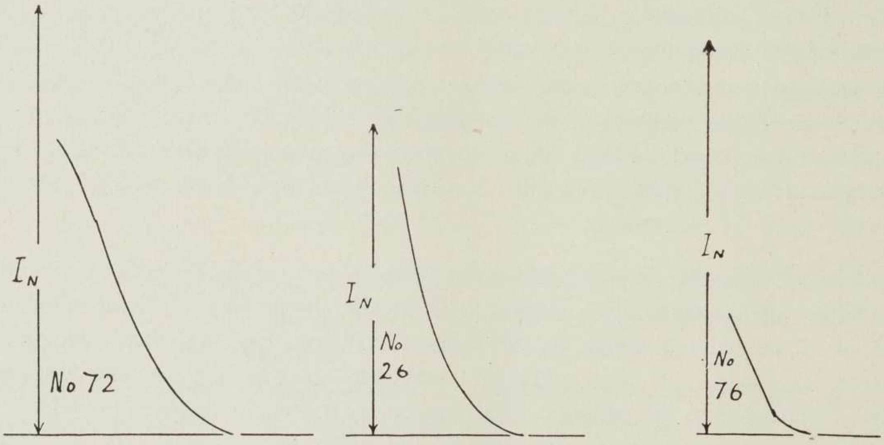
| Pulse No. | Measured ordinates (0.4 sec. intervals). |
|---|---|
| 72 .... .... .... | 20.5, 18.0, 15.2, 13.0, 10.6, 9.0, 7.0, 5.0, 4.0, 3.0, 2.2, 1.6 |
| Power Ratios .... | 1.19, 1.24, 1.17, 1.33, 1.21, 1.34, 1.46, 1·28, 1.36, 1.35, 1.43. |
| Exponential .... | Mean 1.30±0.8 half-life 1.05 sec. |

| Pulse No. | Ordinates (1.0 sec. intervals). |
|---|---|
| 26 .... .... .... | 29.7 (?), 20.0, 10.4, 5.1, 2.0. |
| Ratios .... .... | 1.74, 2.31, 2.29, 2.76. |

Doubtful if exponential.

| Pulse No. | Ordinates (0.4 sec. intervals). |
|---|---|
| 76 .... .... .... | 9.7, 7.3, 5.1, 2.9, 1.4, 0.7. |
| Ratios .... .... | 1.39, 1.50, 1.85, 2.14, 2.04. |

Not exponential.



Text Fig. 4.—Tails of Pulses, Nos. 72 (exponential), 26 (doubtfully exponential), and 76 (not exponential). $I_N$=Set noise current.

Between three quarters and nine-tenths of the curves reproduced in text fig. 4 were examined.

TABLE 1.

Half Lives of Exponential Pulses.

| Half-life (sec.) .... | 0.4— 0·6 | 0.6— 0·8 | 0.8— 1·0 | 1.0— 1·2 | 1.2— 1·4 | 1.4— 1·6 | 1.6— 1·8 | 1.8— 2·0 | 2.0— 2·2 | Over 2·2 |
|---|---|---|---|---|---|---|---|---|---|---|
| No. of pulses .... | 5 | 8 | 12 | 13 | 8 | 7 | 3 | 0 | 2 | *Nil* |

The times taken for the radiated power to decrease to half in the 58 pulses assumed to have exponential form, are set out in Table 1. It will be seen that the range of half-lives has definite limits and tends to concentrate about a value of one second. It is the task of theory to relate this result to the conditions in the region of the solar atmosphere where the noise is generated. Whether the variation in half-lives is attributable to a varying density of protons relative to electrons or to some other factor such as the distribution of electron density in the region about the source can only be decided when considerable theoretical advances have been made. When this question has been clarified, observation of the half-life should provide valuable information regarding the solar atmosphere.

Pulses occurring consecutively or within a short interval may or may not come from the same source or region. If they do, similar half-lives are to be expected. Thirty such pulses were of interest from this viewpoint and they are listed in Table 2.

TABLE 2.

Half-lives of Consecutive Pulses.

| | | | |
|---|---|---|---|
| 27–5–47 | 30 sec. | (con.) | 0 .75, 0 .65 |
| 4–6–47 | 30 sec. | (con.) | 1 .4, 0 .9 |
| 22–7–47 | 30 sec. | (con.) | 0 .9, 0 .9 |
| 23–7–47 | 1 min. | (con.) | 1 .2, 0 .85 |
| 25–7–47 | 30 sec. | (con.) | 1 .1, 1 .1 |
| 7–8–47 | 30 sec. | (con.) | 0 .7, 0 .8 |
| 7–8–47 | 30 sec. | (con.) | 0 .8, 1 .3 |
| 12–8–47 | 40 sec. | | 1 .2, 1 .75, 1 .35 |
| 30–9–47 | 5 min. | | 1 .0, 0 .85, 0 .9, 1 .0, 0 .5, 1 .1 |
| 30–9–47 | 1 min. | | 0 .9, 1 .05, 1 .0 |
| 30–9–47 | 30 sec. | (con.) | 1 .7, 1 .1 |
| 30–9–47 | 30 sec. | | 0 .9, 1 .8 |

There are seven instances of differences greater than 0.3 sec., which is considered to be above the limits of error, as against nine (if the first four pulses of 30. 9.47 are counted as three instances) of agreement within 0.1 sec. x. The proportion of differing half-lives is too great to provide firm support for a conclusion that only one source covering a limited region is responsible for radiation at any given time.

Eight pulses, including the six consecutive pulses on 30. 9.47 occurred in disturbances which were judged to be of a type and magnitude probably coincident with solar flares, though no flare reports confirm this assumption. Their half-lives do not differ significantly from the remainder.

Since the rising portions of several pulses were suitable for magnification, tracing and analysis, an attempt was made to interpret two of them in terms of exponential functions, with no resulting success. This is not surprising since the influence of any exciting agent may at the initiation of radiation be varying in an unknown manner.

Attempts to analyse pulses occurring in Type I. radiation are discussed in the next section.

## 7.—DISTINCTIONS BETWEEN TYPE I. AND TYPE II. RADIATION AND THE NATURE OF TYPE I. PULSES.

The initial classification of two components made in 1946 on the basis the period for which a high level is sustained was not adequate for the more informative records obtained in 1947. A characteristic of Type I. radiation appeared to be the superposition on a more or less high level of small, brief, pulses occurring more frequently than those observed in the Type II. disturbances. The observation of 10–3–47 showed the presence of these pulses in conjunction with a very high background level. The Type I. observed on 20–6–47 and 26–9–47 was characterised by these pulses in conjunction with a relatively low general level. Since the observation of the pulses with or without high background constituted evidence of a long continued disturbance, this characteristic assumed dominant importance in classifying the nature of the disturbance. Hence pulsing of similar type observed for short periods, for example for ten minutes on 25–7–47, was classified Type I. rather than Type II. Similar distinctions have been made by C. W. Allen ([8]).

While therefore the presence, or otherwise, of a high background level is of importance and indeed has been made a basis for distinction between radiation conditions, this section deals primarily with the distinction between the types of pulsing characteristic of the two types of disturbance.

One of the first investigations was of the duration of the pulses at the level of half maximum power. In this connection 208 pulses occurring in Type II. disturbances were measured as to duration and maximum power and, similarly, 178 pulses occurring on 10–3–47 and 11–6–47 in Type I. disturbances. This was done by projecting with up to 30x magnification. In the case of the latter type of pulses accuracy is low owing to the width of the trace on the film being of the same order as the pulse height.

The results are plotted in text fig. 5, the individual values for Type II. and the limits and average values only for Type I. being shown. A plot of the relative energy emitted in the pulses is shown in text fig. 6. It is clear that Type I. pulses are in general markedly distinct in appearance from Type II., although there is overlap in actual values observed.

The pulsing frequency is also different. The frequency of Type I. pulses averages from 10 to more than 20 per minute, while Type II. pulses average from 4 to 10 per minute.

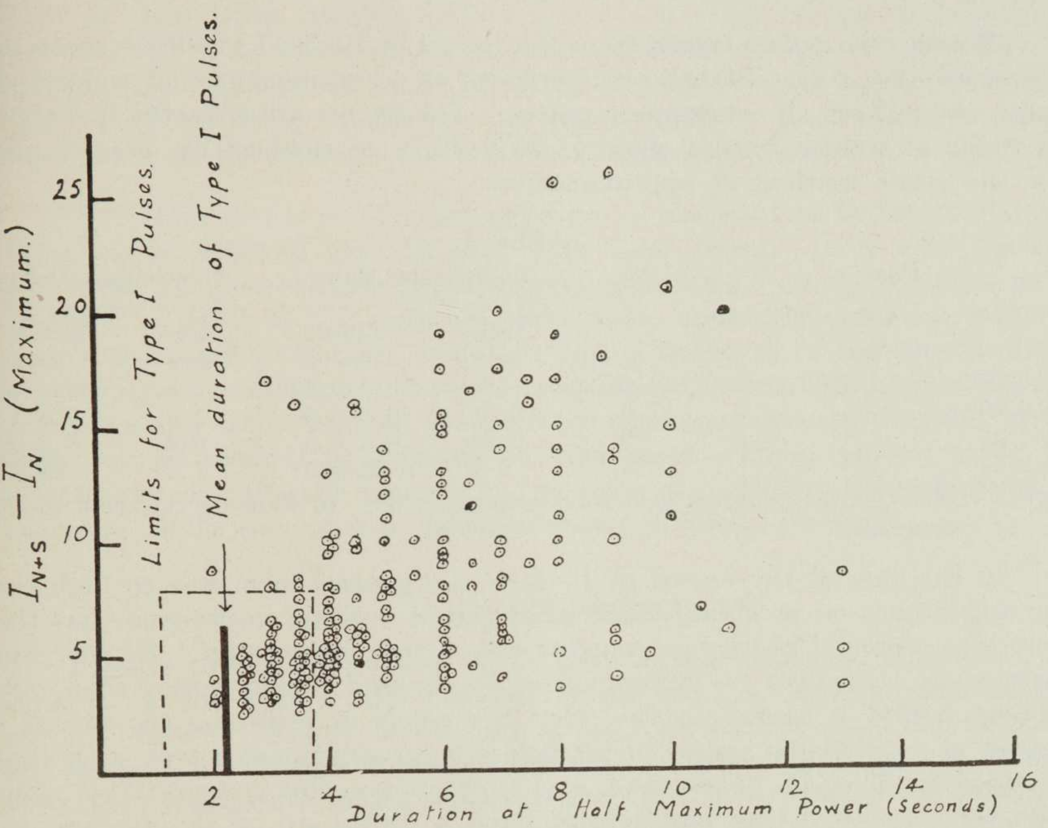
A further point of interest is the decay curve for Type I. pulses. Here again satisfactory accuracy is unattainable in most cases, since few pulses are suitable for tracing and the length of falling trace is usually too short for analysis by the method of section 6.

This was not the case for the record of 26–9–47 from which 21 pulse tracings were analysed by converting the ordinates to a scale of power. It is not possible to judge whether or not the curves are exponential, but they are assumed to be so in what follows. Making the assumption that the foot of the traced portion was the true zero for the pulse, the mean half-life of 21 pulses was determined as 0.4 sec. with extreme limits 0.25 sec. and 0.5 sec.

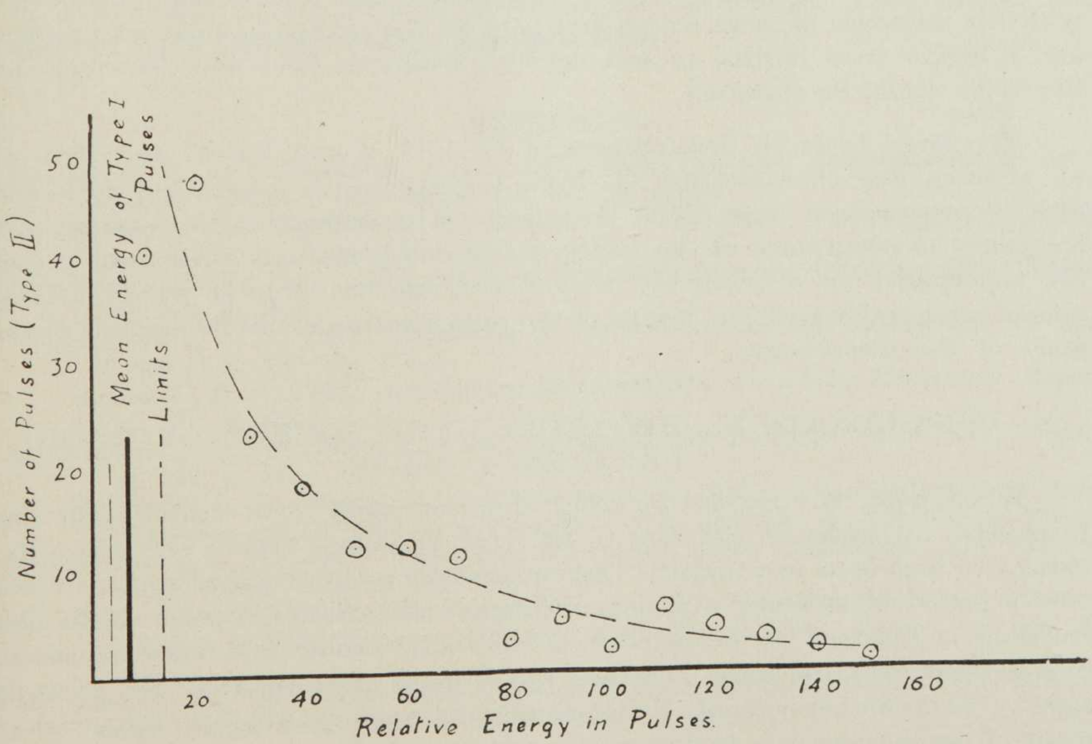
It is important to determine whether this result is significant, or whether it is due to the assumption that the pulses *as observed* are the *actual* pulses emitted instead of the result of overlapping of pulses having a considerably lower baseline, *e.g.*, the line $I_N$. If the latter assumption is made for the record of 26–9–47, the pulse half-lives will be increased about three times to an average of about 1.2 sec., or the same order as Type II. pulses. The range of half-lives, however, is from 0.35 sec. to 3.0 sec., which is wider than the observed range of Type I. pulses.

Other Type I. pulses could not be analysed in terms of power and an estimate of half-life could only be made by determining from the unconverted trace the time interval over which the ordinate decreased to half. It is found by comparison with the correct method of analysing traces, that this approximation overestimates the half-life by from 30–50%, depending on the values of $I_N$ and $I_{N+S}$.

For nine pulses observed on 25–7–47 the mean half-life was about 0.55 sec. (uncorrected for overestimate) with limits 0.3–0·7 sec. assuming true pulses observed above a general background. If the tops of overlapping pulses were actually being observed the mean life (uncorrected) is about 0.9 sec. with limits 0.5–1.2 sec.



Text Fig. 5.—Values of duration at half maximum power for Type I and Type II Pulses.



Text Fig. 6.—Comparison of Energy in Type I and Type II Pulses.

Six pulses observed on 20–6–47 treated as true pulses yield a mean (uncorrected) of 0.5 sec. with limits 0.3–0·8 sec., as against a mean for overlapping pulses (uncorrected) of 1.7 sec. with limits 1.3 to 2.0 sec.

Finally two pulses traced from the record of 10–3–47 yielded a mean (uncorrected) of 0.6 sec. if taken as superposed on a high background and a rough mean about 3 sec., if overlapping pulses. The results are collected in Table 3, in which all values, except those of 26–9–47, were reduced by 30% to allow for the crude method of approximation.

TABLE 3.

| Date. | No. | Superposed Pulses. | | Overlapped Pulses. | |
|---|---|---|---|---|---|
| | | Mean sec. | Limits sec. | Mean sec. | Limits sec. |
| 10–3–47 | 2 | .... | 0.4–0.45 | .... | about 2.0 |
| 20–6–47 | 6 | 0.35 | 0.2–0.5 | 1.1 | 0.8–1.4 |
| 25–7–47 | 9 | 0.35 | 0.2–0.5 | 0.6 | 0.3–0.8 |
| 26–9–47 | 21 | 0.4 | 0.25–0.5 | 1.2 | 0.35–3.0 |

NOTE.—The estimated half-lives have been reduced by 30% to allow for the crude method of measurement.

In the case of the record of 10–3–47 the general level was so high that the appearance on it of individual pulses gave a strong impression that they were true pulses of radiation occurring above the background. In the other cases while they give an impression of superposed pulses rather than overlapping pulses, it cannot be said that the result of assuming the record to consist of overlapping pulses yields half-lives grossly inconsistent with those obtained for Type II. pulses, and, as a consequence, this interpretation rather than the conclusion that half-lives of Type I. pulses are on the average considerably shorter than Type II. pulses cannot be ruled out. Additional experimental evidence is highly desirable on the question. The conditions under which pulses of radiation are emitted more frequently and for much longer intervals than in the short period disturbance are undoubtedly connected with the influence of large active sunspots on the overlying solar atmosphere and a higher than normal proton density, magnetic field and electrical conductivity would be expected.

The large Type II. disturbances of 16–5–47, 4 and 5–6–47 and 30–9–47 all show pulses characteristic of Type I. disturbance intermixed with and often superposed on large Type II. pulses. The differences in duration and frequency of occurrence of the two types are very marked. All these pulses are superposed on a relatively slowly varying background which attains a level comparable with the height of the pulses within about 30 seconds of the start of the disturbance.

## 8.—CONSIDERATIONS REGARDING THE SOURCE OF RADIO FREQUENCY NOISE.

When noise is observed to occur simultaneously with visible solar disturbances, the noise, in contrast to the H∝ emission, begins very abruptly, rising to a high level in a matter of seconds, whereas the H∝ emission increases over a period of as many minutes. Since in such cases increased ultraviolet emission is assumed to be responsible for both visible and noise emission, it is evident that the noise increases much more abruptly than the exciting agent. This can happen only if the emission of noise results from the development of oscillations in a region of the solar atmosphere whose normal equilibrium has been upset by the gradually increasing influence of the exciting ent.

If this view is rejected in favour of the idea that the emission of noise follows closely the magnitude of the exciting agent, then it must also be assumed that short pulses of ultraviolet light and also of corpuscular emission occur at reasonably regular frequencies of the order of ten to twenty per minute. No other observations of solar phenomena support this view. In addition, the exponential mode of decay of emitted noise power, if a direct reflection of the decay of the exciting agent would be much harder to understand than on the basis of the assumption made in Section 6.

More than one type of noise radiation is observed to be emitted during disturbances believed simultaneous with solar flares. It is also observed that Type II. disturbances appear superimposed on Type I. emission, as for example on 10–3–47. It appears then, that, under the influence either of greatly increased ultraviolet radiation during flares, or of the corpuscular or electromagnetic radiation presumably responsible for the high level of emission over large and active sunspot groups more than one region of the solar atmosphere can be excited to emission of solar noise. These regions would presumably be at different heights in the solar atmosphere, electron densities, magnetic fields and proton densities being different for each.

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